Noise Reduction/Mode Isolation with Adaptive Down Conversion (ADC)

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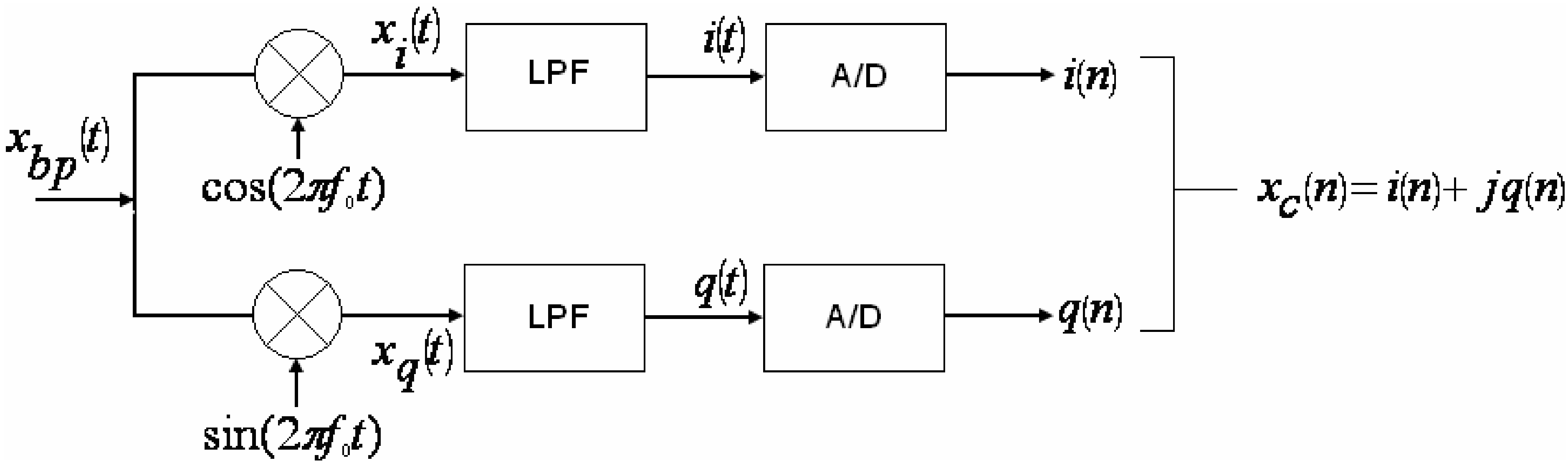
Summary

Adaptive down conversion (ADC) analysis mimics down conversion in radio frequency (RF) quadrature data acquisition. ADC differs from the RF quadrature application by using a time-dependent mixing frequency. Current ADC application uses the frequency (i.e., velocity) extracted from the Fast Fourier Transform (FFT) spectrogram analysis. For the data analysis, the low-pass filtering step decreases band width noise and isolates the selected mode (i.e., the mode from which the velocity was extracted in the FFT spectrogram). Following the RF quadrature procedure, additional analysis steps reconstruct the isolated mode and its quadrature data set that is rotated 90°. Phases, frequencies, and velocities are then computed in standard procedure. This technique is applicable to quadrature and triature photon Doppler velocimety (PDV).

Application to Thermos Confirmatory data from PRAD is presented.

Radio Frequency Down Conversion



Reconstruction

$$I(t) = i(t)\cos(2\pi f_0 t) + q(t)\sin(2\pi f_0 t)$$

$$Q(t) = i(t)\sin(2\pi f_0 t) - q(t)\cos(2\pi f_0 t)$$

$$\Phi = \tan^{-1}\left(\frac{Q(t)}{I(t)}\right)$$

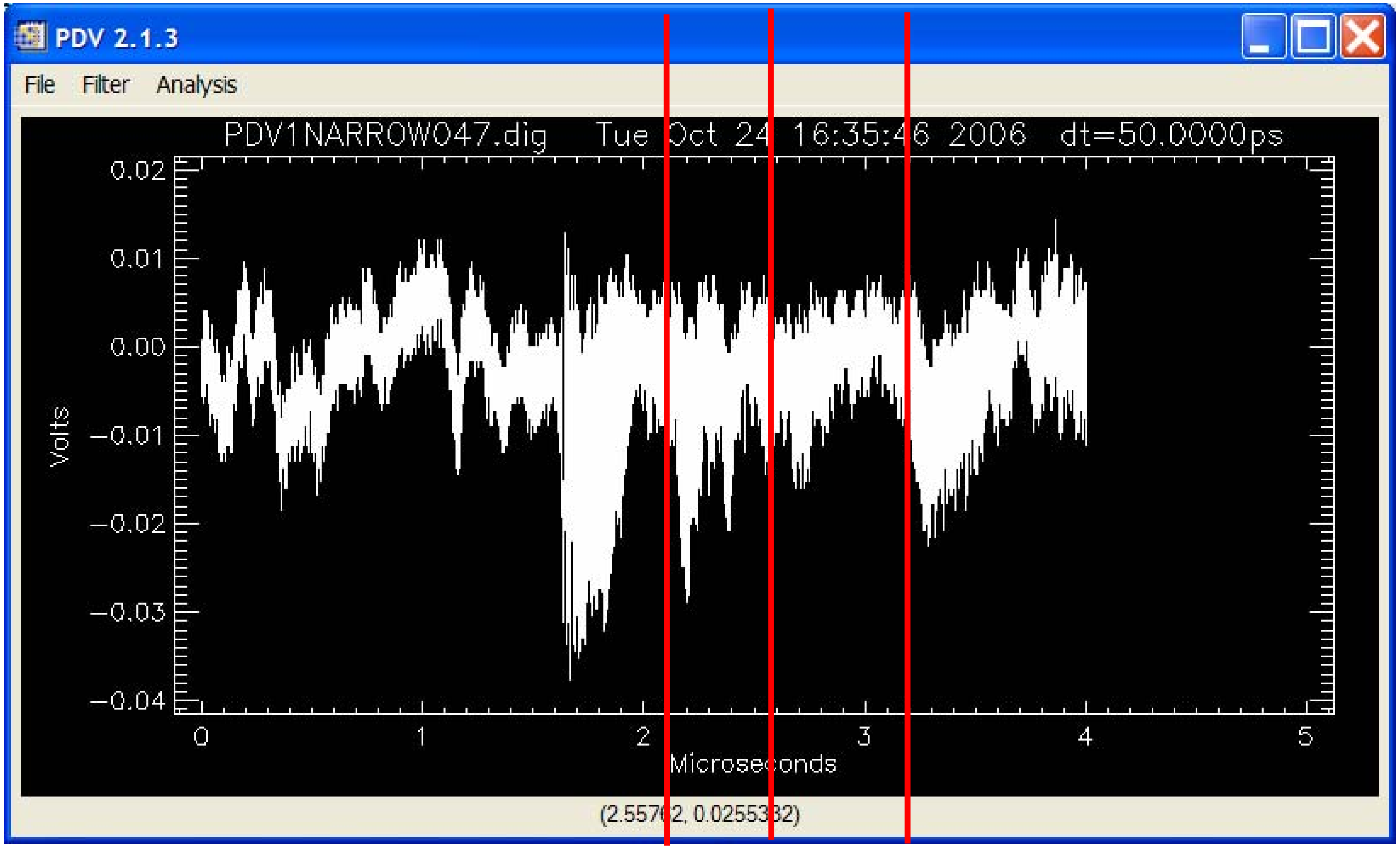
Adaptive Down Conversion

Replace $2\pi f t$ with $\phi_m = \int 2\pi f_{FFT}\, d\tau$

And eliminate A/D

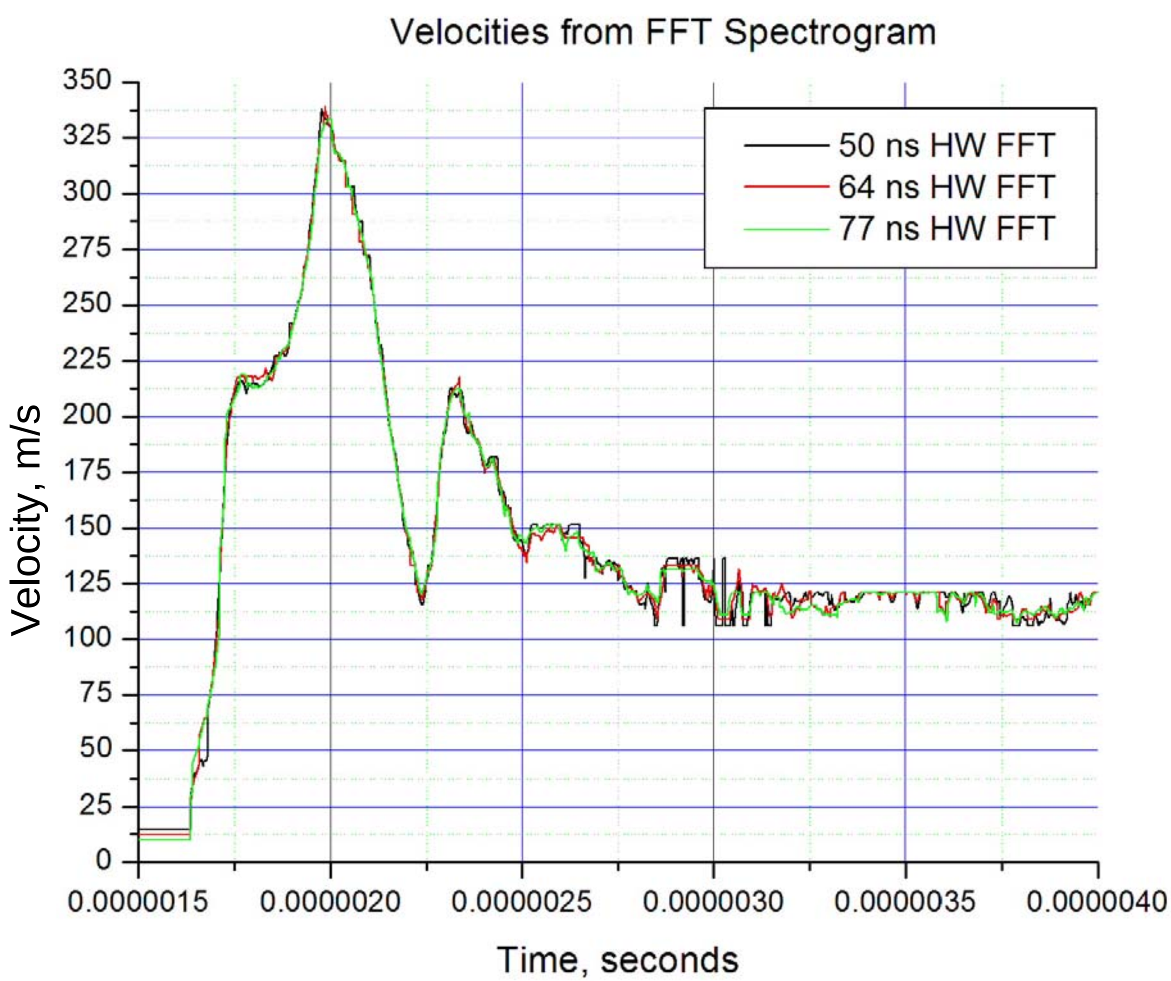
$$V(t) = \frac{\lambda}{4\pi} \frac{d\Phi(t)}{dt}$$

Thermos Confirmatory Data from PRAD



The velocity calculation based on the unfolding of the phase function is more sensitive to noise than the power basis of the FFT spectrogram. The decrease in signal around 2, 2.5, and 3 μs indicates large uncertainties in velocity calculations.

FFT Velocities for PDV Confirmatory Data from PRAD



The legend refers to FFT window; FFTs computed with Hanning window. The shorter windows provide better time resolution, while the larger windows provide better frequency resolution.

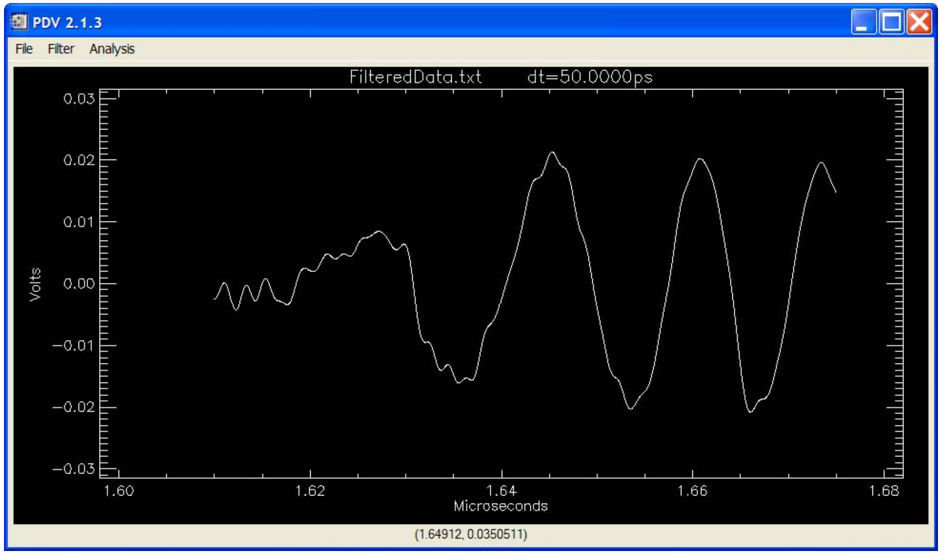
The phase-based calculations have promise to improve time resolution, but are more sensitive to noise than the power-based FFT approaches.

ADC was developed for mode isolation and to improve signal-to-noise ratio in the phase-based calculations. Sample results of improving signal-to-noise and mode isolation (i.e., eliminating unwanted modes) is shown next.

Noise and Low-Frequency Modes

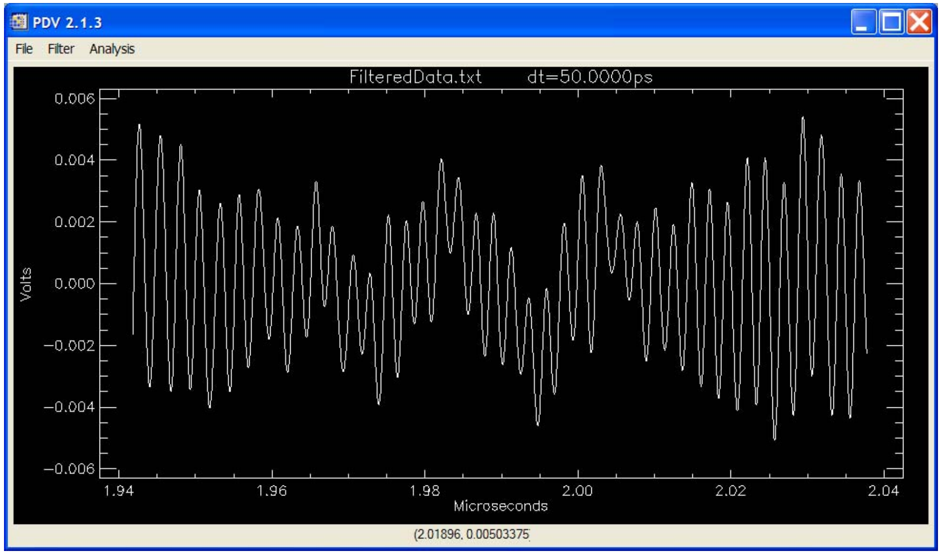
Zoomed view at shock break out

These data were high-pass filtered at 30 MHz and low-pass filtered at 600 MHz. Sufficient noise remains to distort peaks, troughs, and the wave form in general.



Zoomed view at 2 microseconds

Sufficient low-frequency modes persist to elevate some minima above some maxima.

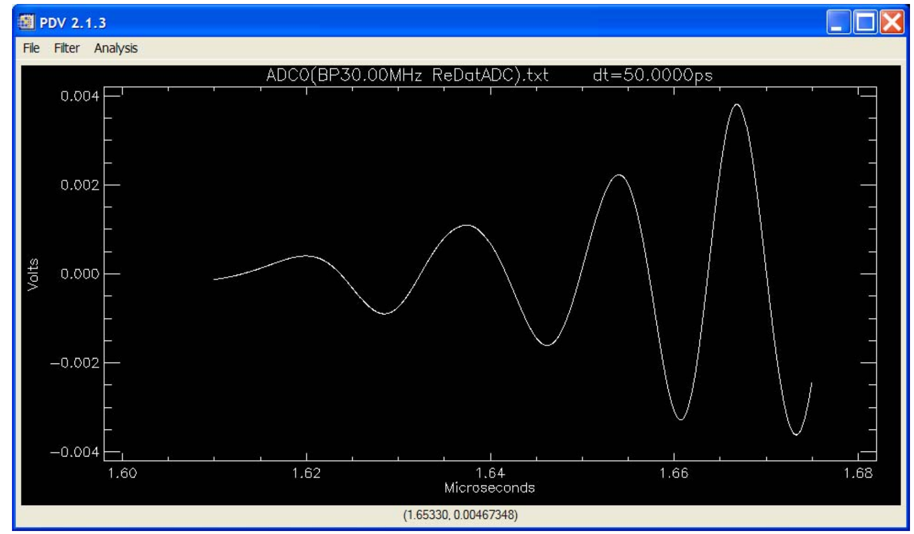


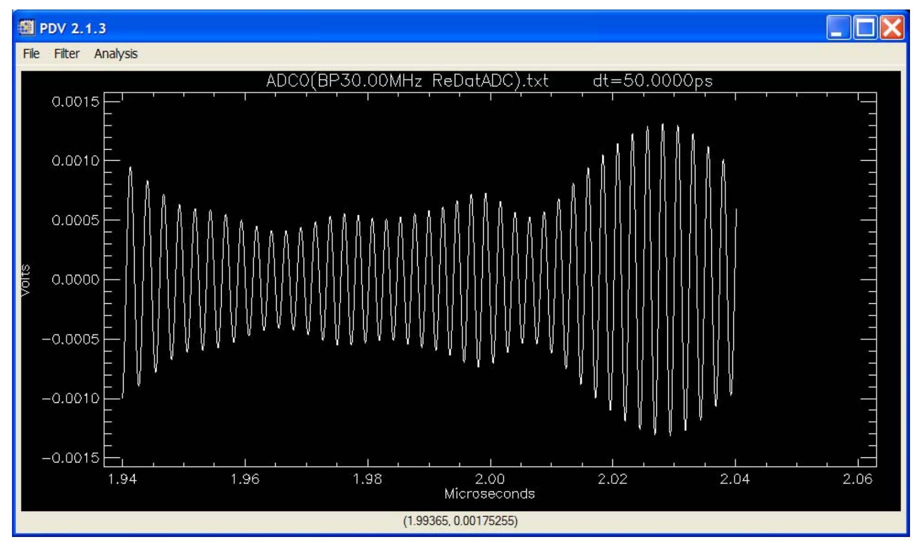
Would be a problem for triature data sets as well.

Zoomed View of Same Regions

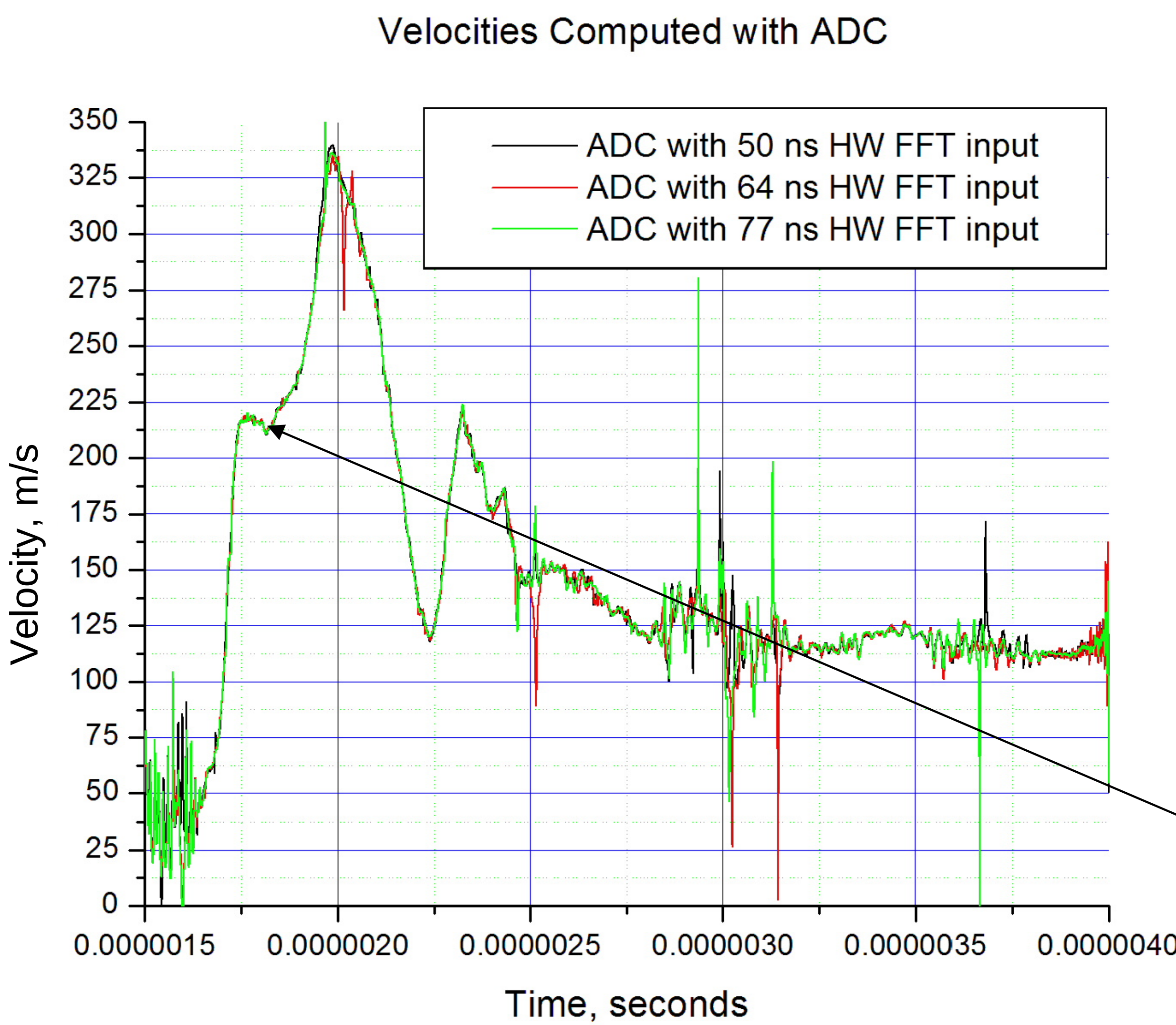
These plots show substantial noise reduction and mode isolation that were achieved with ADC.

Sample plots of ADC velocities are shown next.





Velocities Computed Using ADC, 1

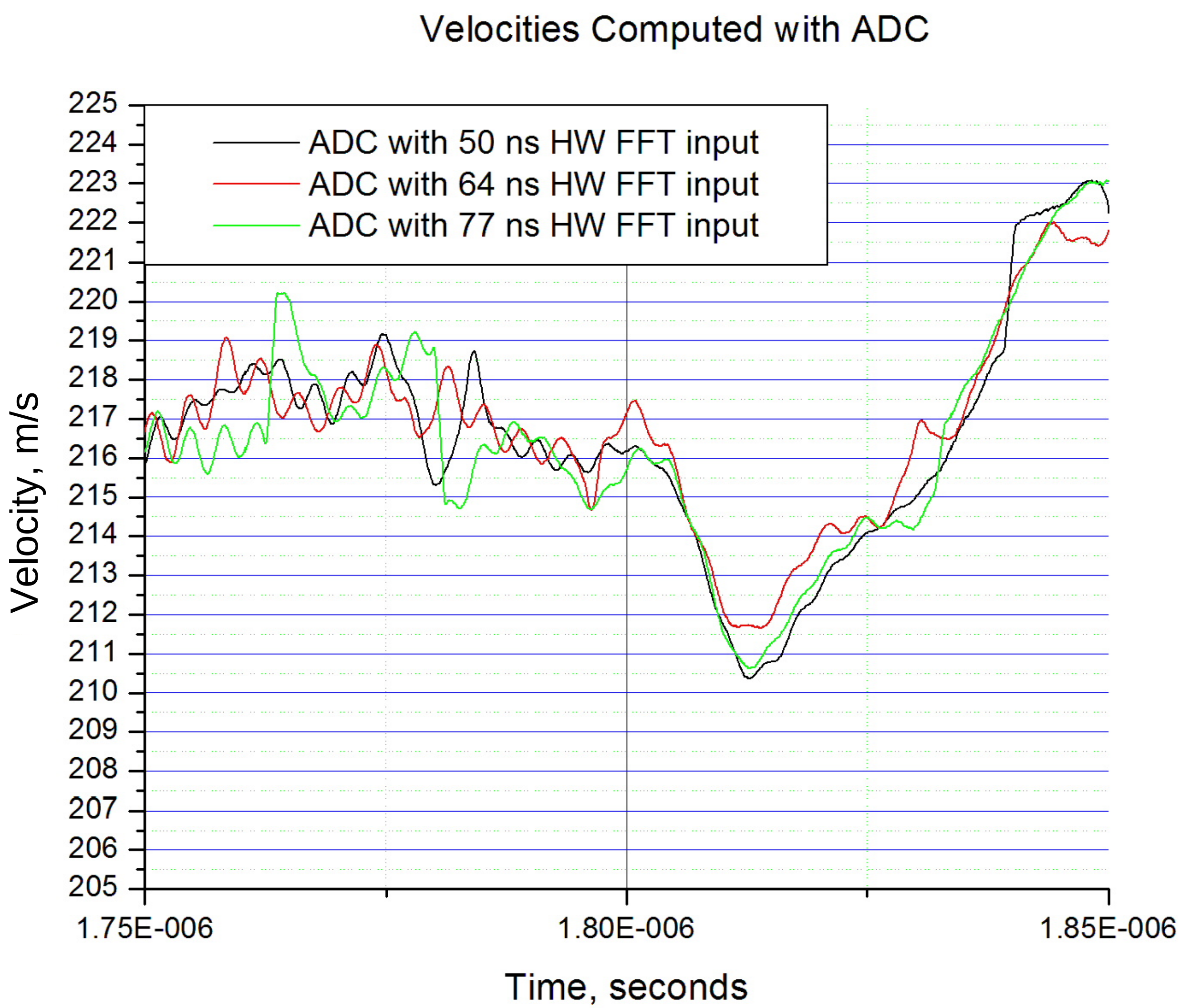


Legend identifies the FFT calculation from which the frequency, $f(t) = v/(\lambda/2)$, is used to generate the mixing function. Data are processed with a 22 MHz band pass (+/- 15 m/s) and 1-ns smoothing in the calculation of the time derivative.

With notable exceptions (the 2, 2.5, and 3 μs), the ADC results are in better agreement than the FFT calculations.

The next viewgraph zooms in on the shoulder.

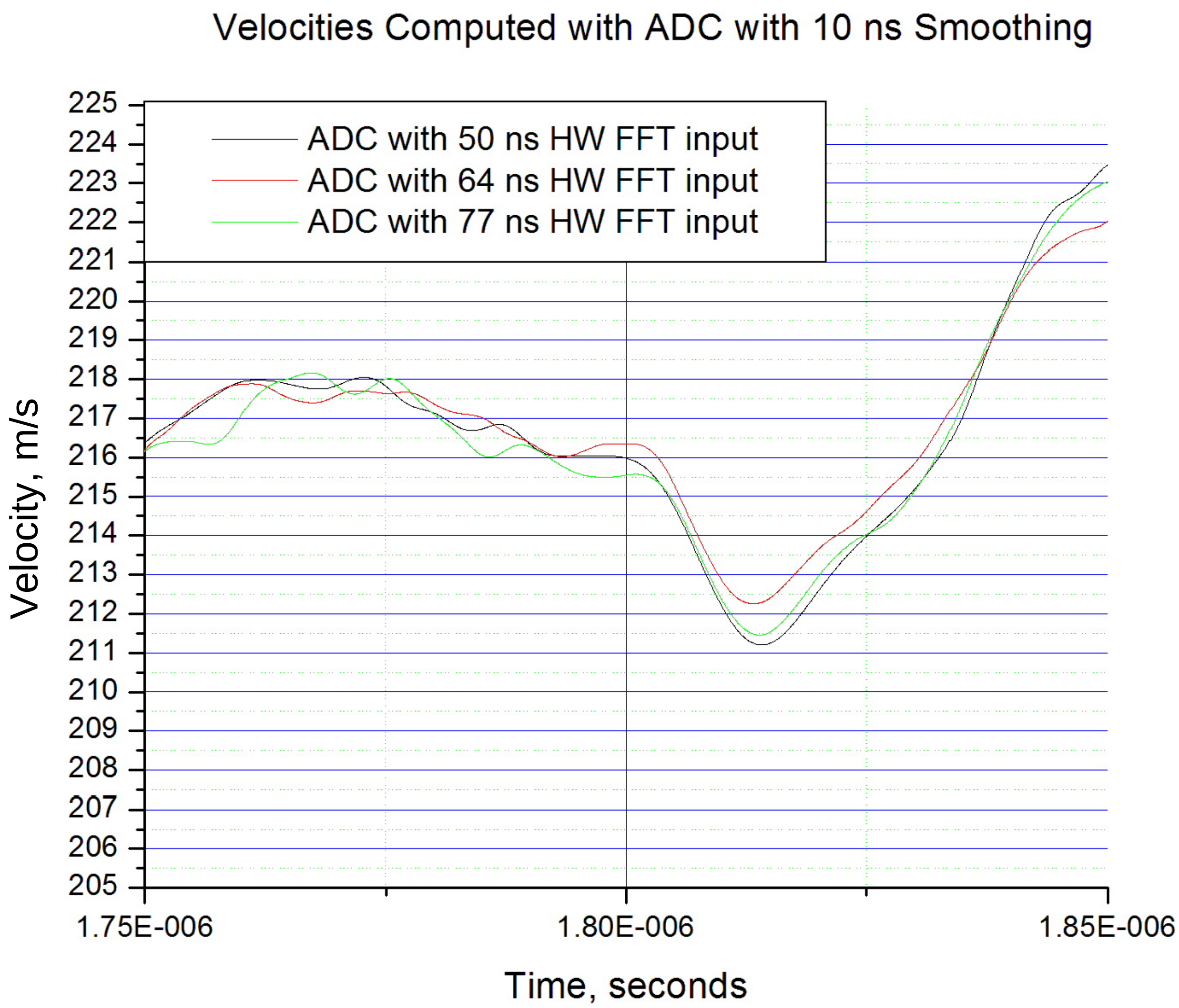
Velocities Computed Using ADC, 2



Zoomed view of shoulder. In general, analysis results within 1–2 m/s agreement.

The next viewgraph zooms in on the shoulder with 10-ns smoothing.

Velocities Computed Using ADC, 3



Zoomed view of shoulder. In general, analysis results within 1 m/s agreement with greater smoothing.

Model for uncorrelated errors (next) predicts greater agreement. We suspect that additional smoothing is limited by natural bandwidth in the data.

Error Model (Uncorrelated)

$$E\left[\left(\frac{\delta v}{v}\right)\right]^2 = \left(\frac{12}{\left(N^3 - N\right)}\right)\left[\left(\frac{\delta t}{\Delta t}\right)^2 + \frac{1}{\omega^2 \Delta t^2}\left(\frac{1}{S/N}\right)^2\right]$$

δt - time jitter

Δt - sample interval

$\frac{S}{N}$ - signal to noise

$\frac{\omega \Delta t}{2\pi}$ - fractional fringe

ω - angular frequency $\propto v$

v - velocity

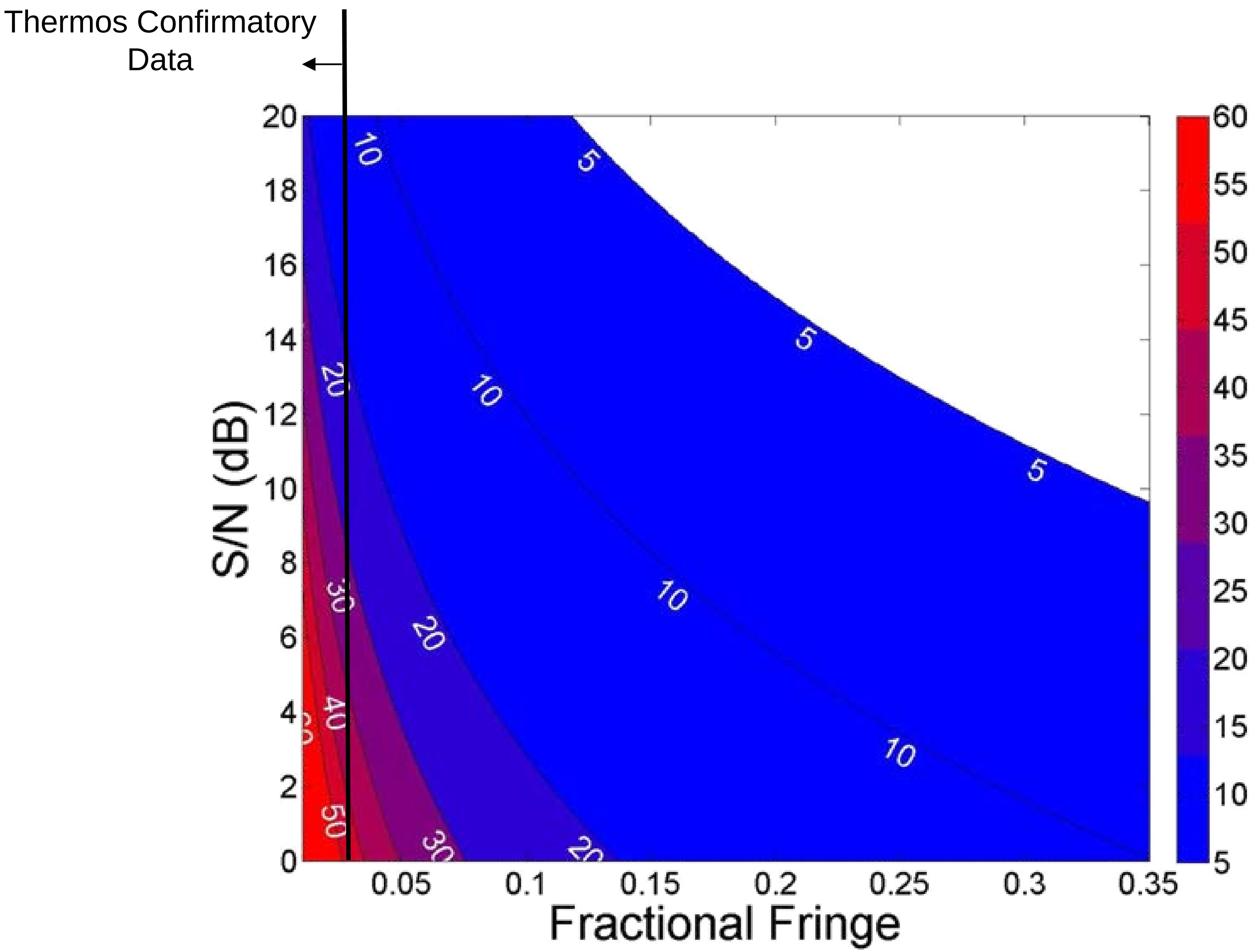
δv - velocity error

Recording system

Data

Analysis

Error Contours for 5 % Accuracy



Conclusion

- ADC calculations depend on prior estimate of velocity of signal. The velocities from the FFT spectrogram appear to be a good estimate from which to calculate mixing phase.
- ADC provides effective noise reduction and mode isolation.
- For the Thermos Confirmatory data, analysis is probably limited by natural bandwidth of the signal (1–2 m/s).
- ADC has been integrated into a user interface that includes standard FFT analysis.
- ADC has already been applied to triature data for mode isolation and noise reduction.
- Some investigations of the low-pass filtered data sets, i(t) and q(t), may be warranted.